A 7-Element K-Band Focal Plane Array

for the Green Bank Telescope

Multi-Pixel Camera Receivers

Gary Anderson, Eric Bryerton, Dennis Egan, Bob Garwood, Glen Langston, Jay Lockman, Matt Morgan, Roger Norrod, Bob Simon, Sivasankaran Srikanth, Galen Watts, Steve White, and many more...

Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

NRAO

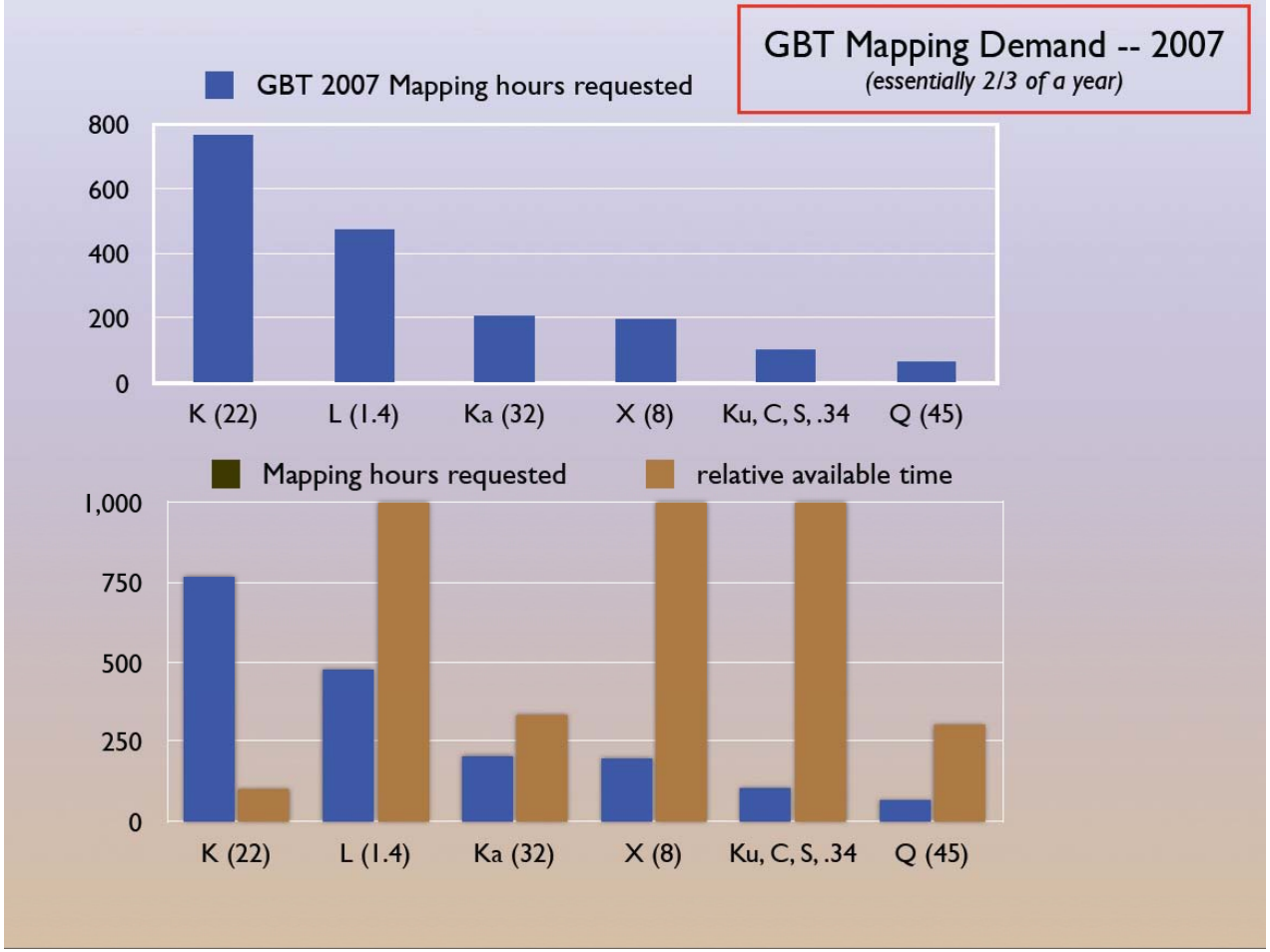
Robert C. Byrd Green Bank Radio Telescope

- 100 Meter Diameter
- Unobstructed Aperture
- Offset Gregorian Optics
- National Radio Quiet Zone (NRQZ)

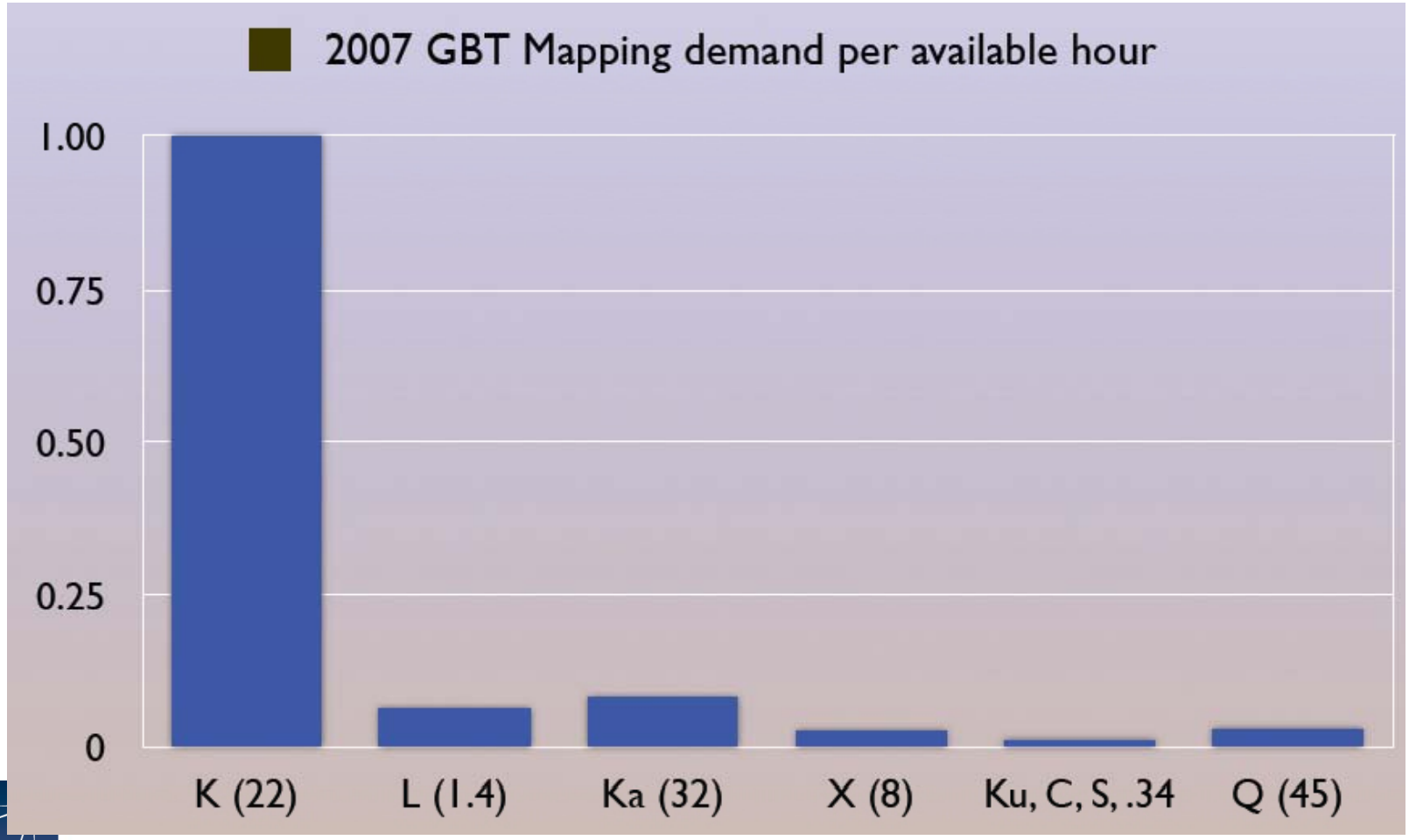
- Large, clean, focal plane lends itself naturally to focal plane arrays.

NRAO

Why Build the First FPA at K-Band?



Why Build the First FPA at K-Band?



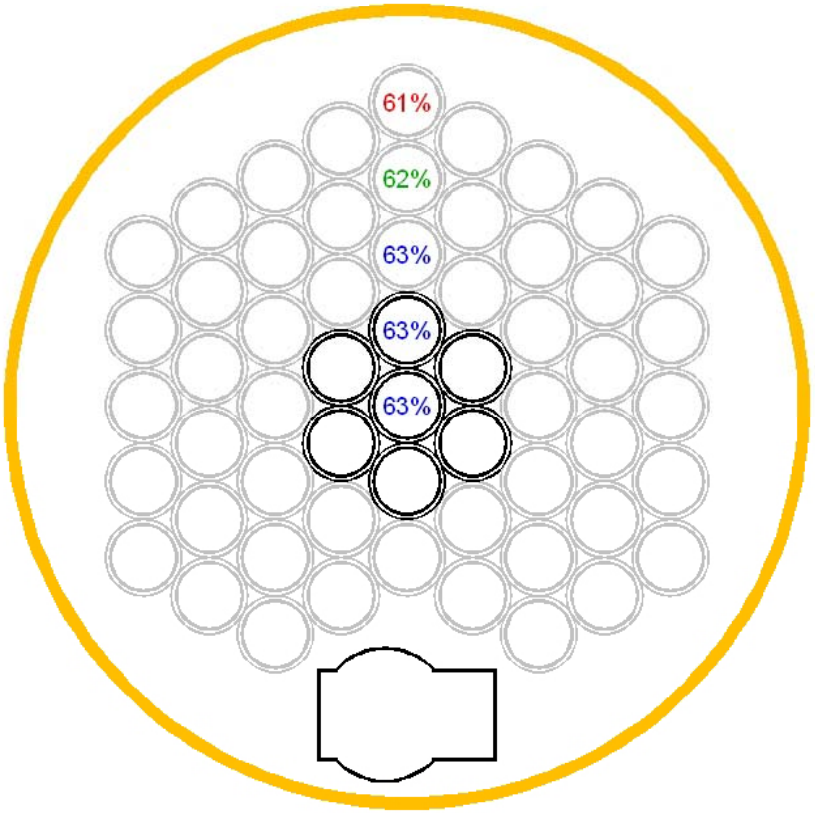
Why Build the First FPA at K-Band?

- We already had many of the parts – project was proposed on a low budget ($1.2M) and fast timetable (3 yrs) based on the premise that many existing components and systems could be reused.

- Can use existing telescope infrastructure (power supplies, LO synthesizers, fiber optic link...)

- Served as a good starting point for a long-term FPA program.

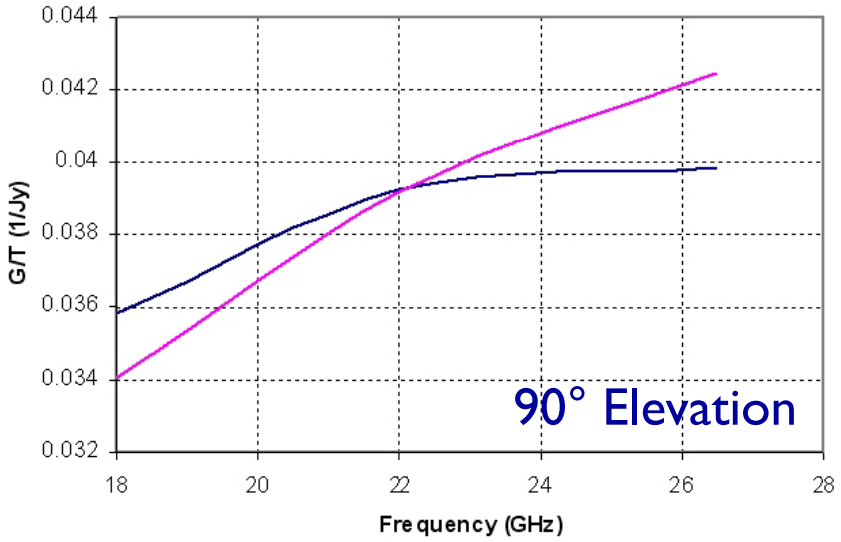
Feedhorn Arrangement

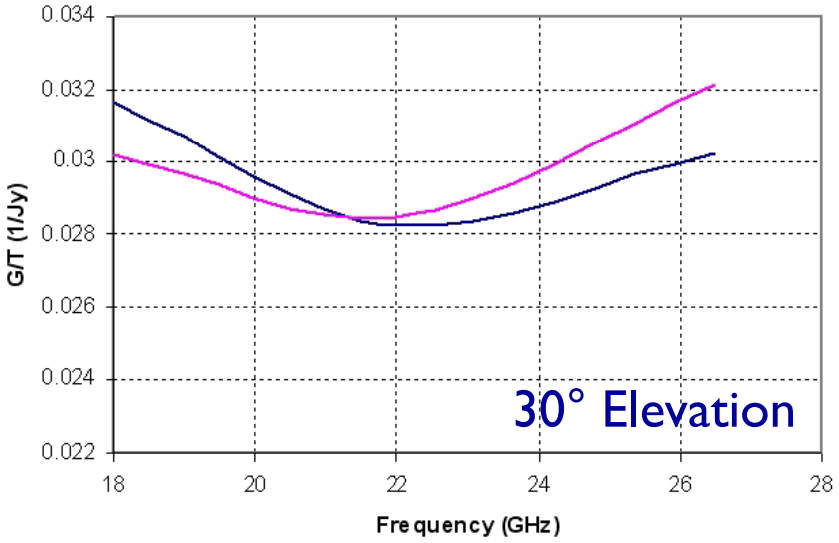


- 36” mounting ring on the receiver turret would support about 60 K-Band feedhorns.
- 3.45” spacing (~2.5 HPBW)
- Original program:
  - engineering development for 60-pixel array
  - construct 7-pixel prototype.

Effect of Shrinking the Feedhorn

Frequency [GHz]	Beam Spacing [HPBW] 3.4" feed	Beam Spacing [HPBW] 2.8" feed
18	2.3	2.0
22	2.7	2.4
26	3.2	2.7





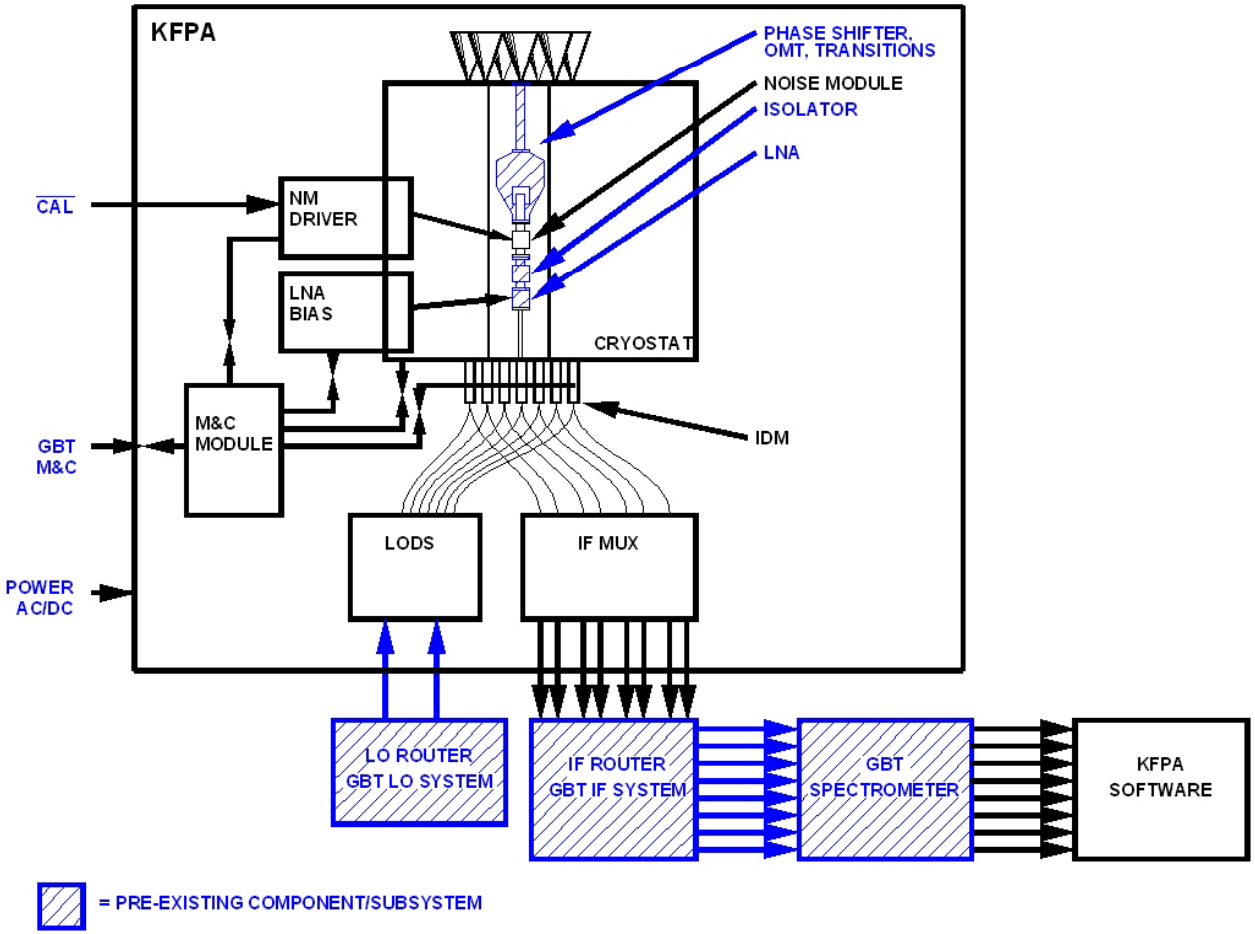
System Baseline Specifications

Specification	Requirement
Frequency Band	18-26.5 GHz (complete K-Band coverage) Can tune up to 27.5 GHz
Instantaneous RF Bandwidth	1.8 GHz (front-end)
Number of Beams	7
T_{RX} (each beam, not including sky)	<25K (75% of band) <35K (entire band)
Aperture Efficiency	>55% (any pixel)
Polarization	dual, circular (axial ratio <= 1dB)
Polarization Isolation	>25 dB
Pixel-to-Pixel Isolation	>30 dB
Headroom	>30 dB (to 1 dB compression point)

Bandwidth Limitations

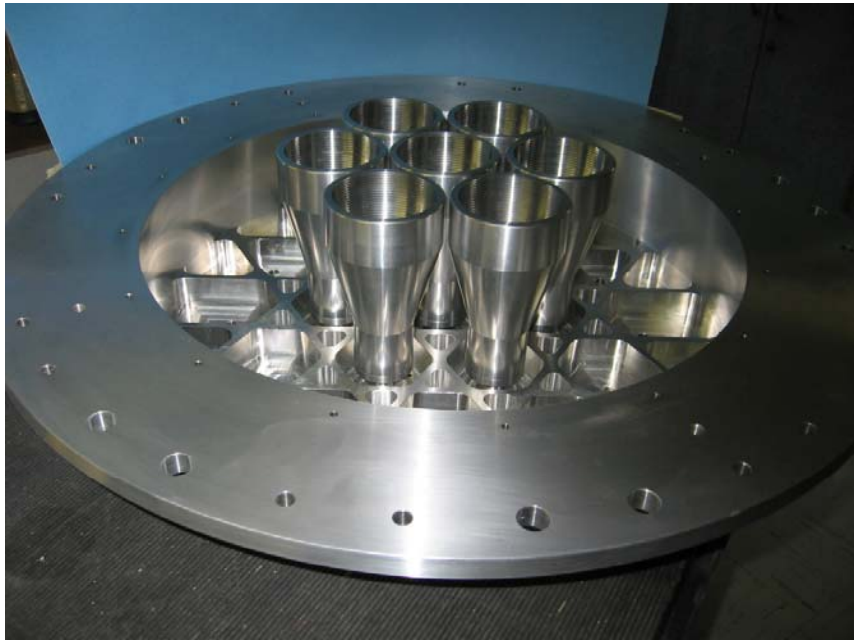
Sub-Assembly	Total Potential Bandwidth	Comments
cold-electronics (feed, OMT, LNAs...)	>8.5 GHz	degrades outside of 18-26.5 GHz
warm analog electronics	1.8 GHz (up to 8 dual-polarized beams)	limited by existing IF transmission system, **requires multiplexing**
digital electronics	800 MHz (4 beams) 50 MHz (8 beams)	limited by existing spectrometer

System Schematic

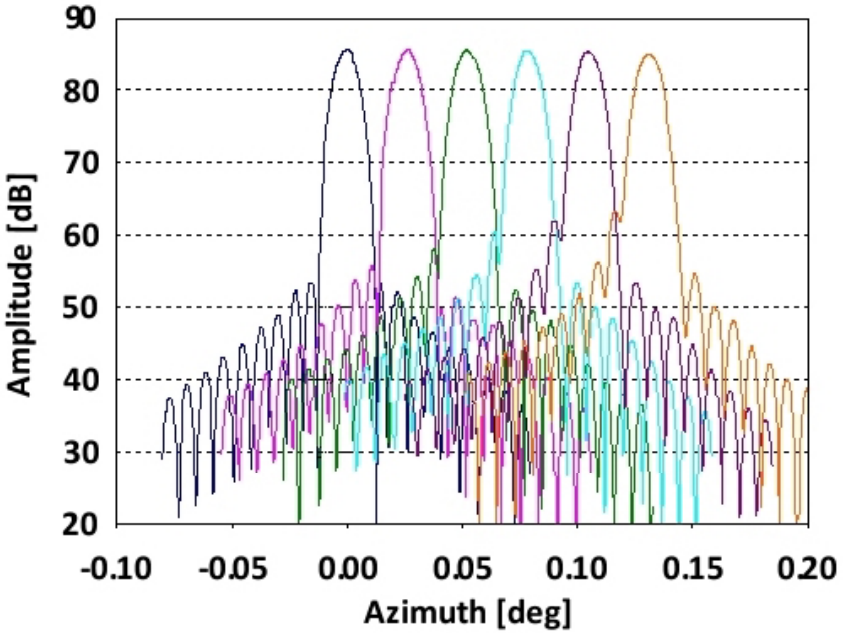


Compact Corrugated Feedhorns

3.4" O.D. Feedhorns

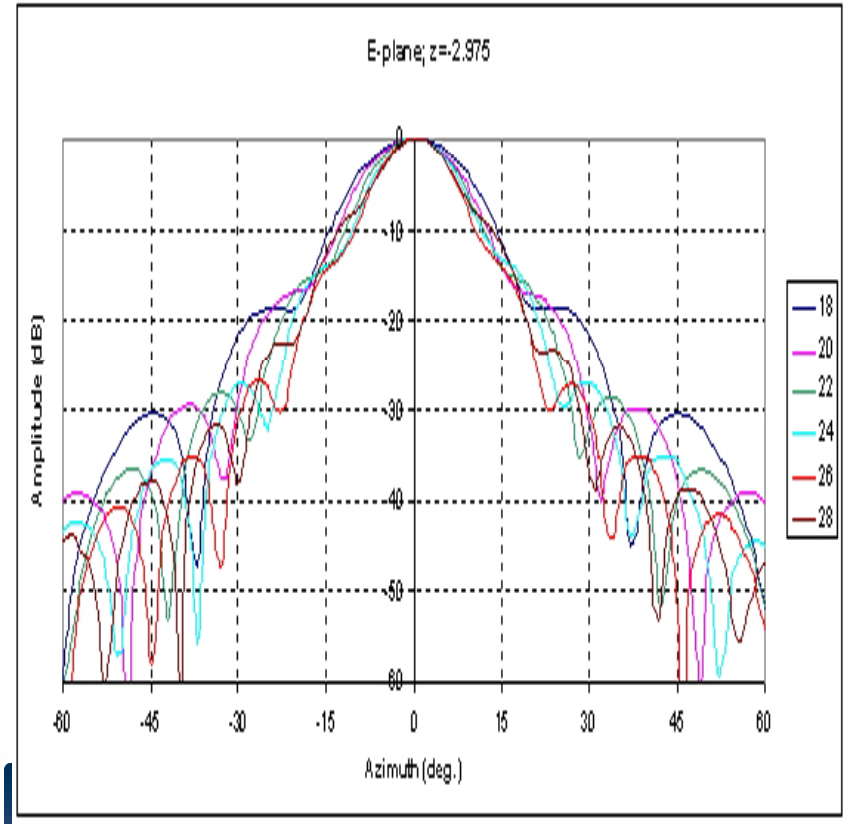


22 GHz Telescope Beams

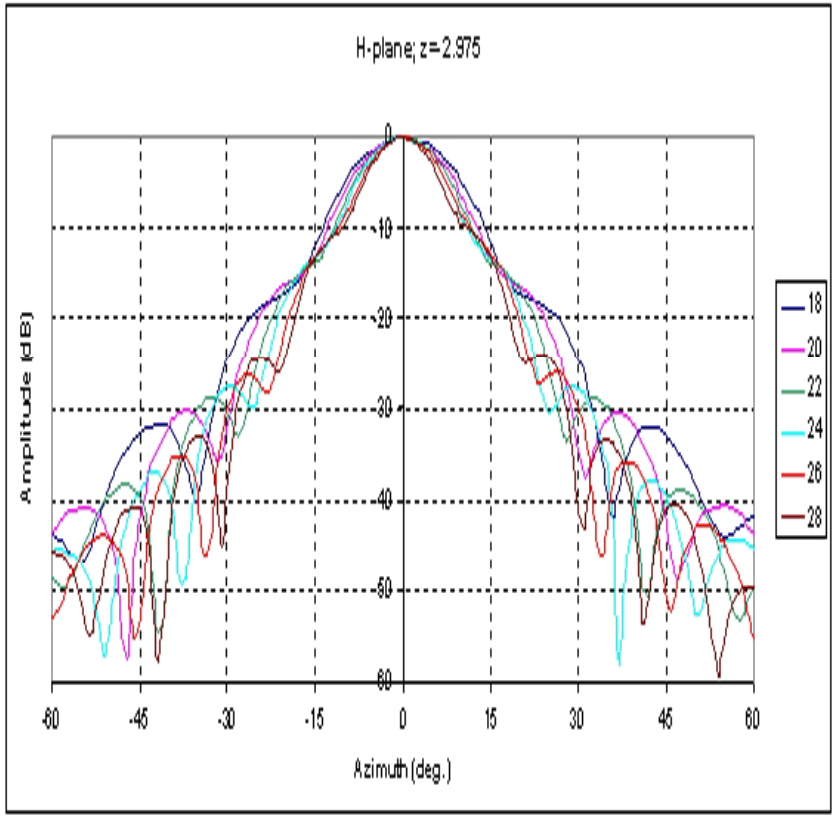


Compact Corrugated Feedhorns – 13 dB Edge Taper

E-Plane Pattern



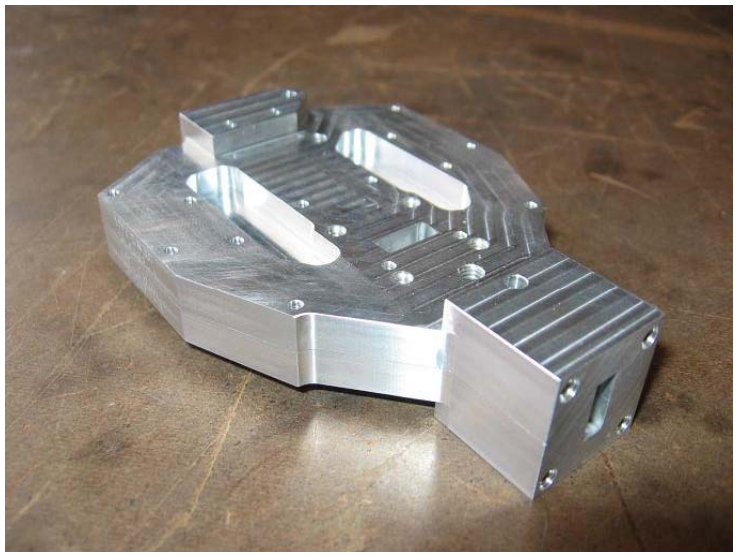
H-Plane Pattern



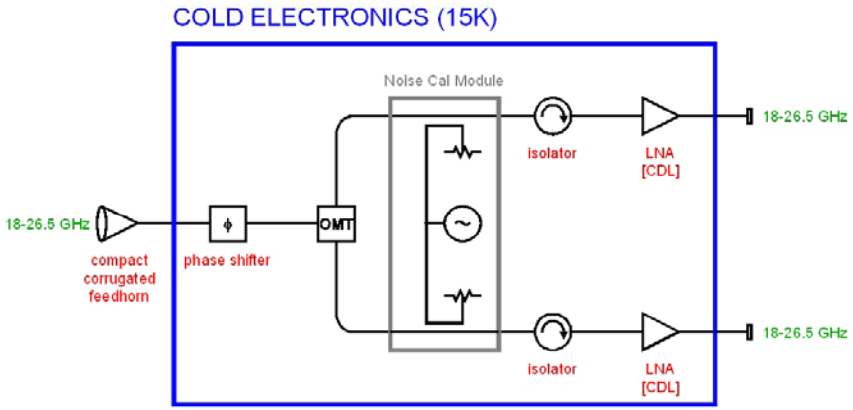
Thermal Gap

- 0.543" circular waveguide
- 0.010" gap with choke groove
- upper half at 300 K, lower at 15 K
- hollow, shaped G10 supports
- optimized for weight, strength, and thermal isolation
- Cuming Microwave PS-102 foam for vacuum seal
- Cuming Eccobond 45 epoxy
- 3-mil Kapton vapor seal

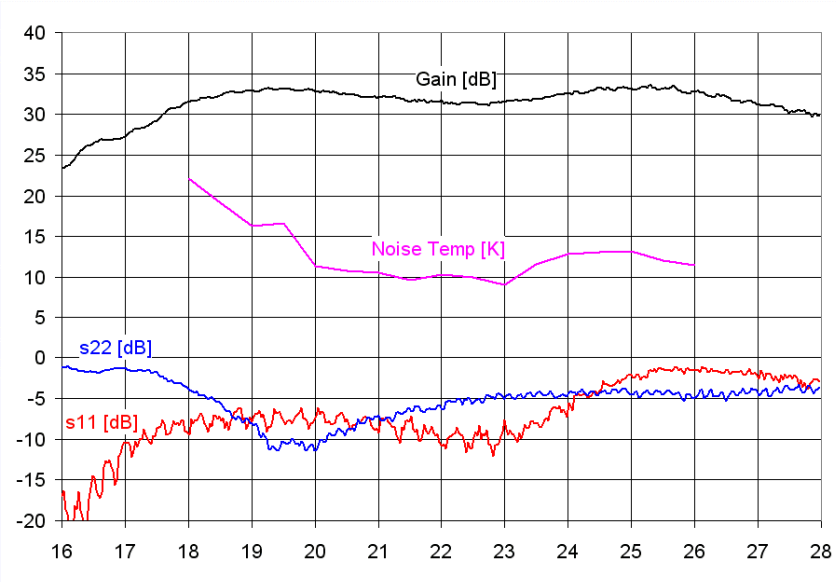
Quadrature Phase Shifter and OMT

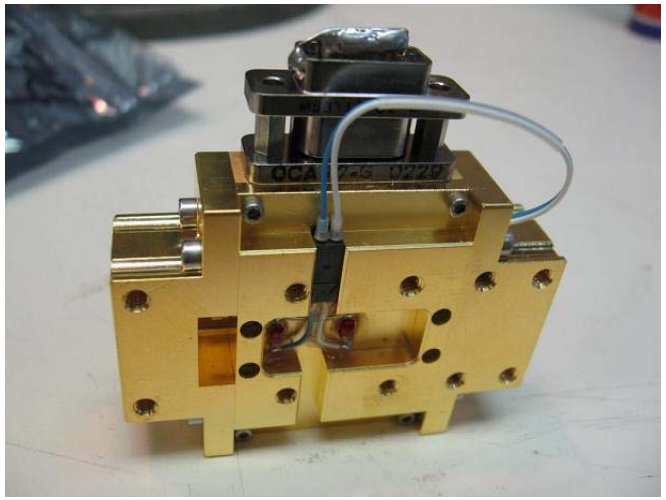


Noise Calibration Source Integrated With Coupler

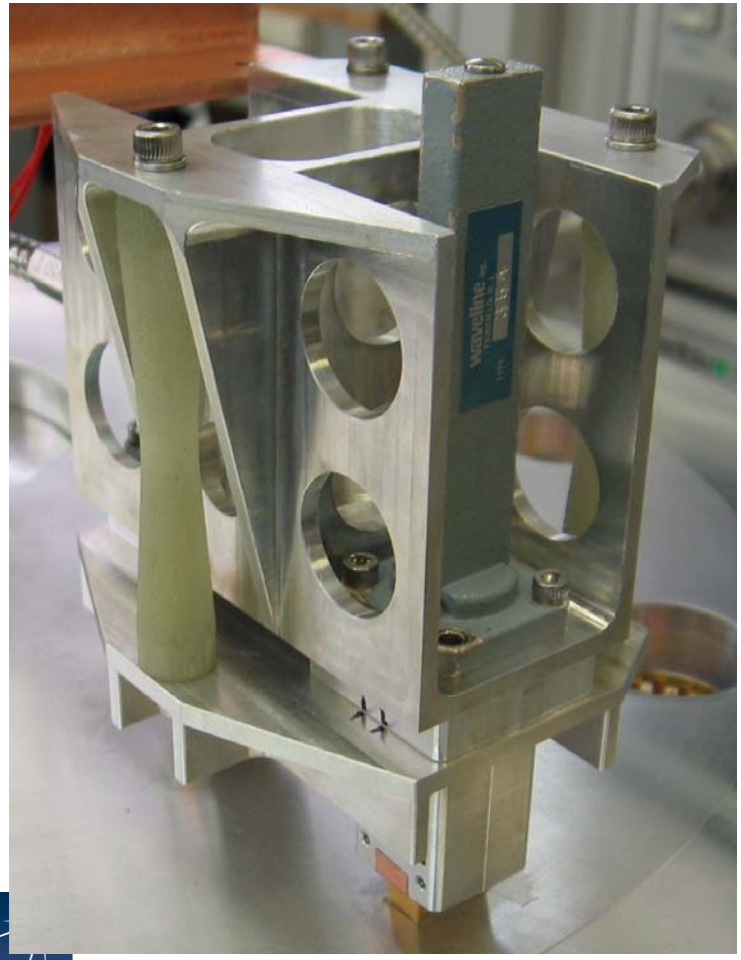


KFPA Will Use Existing EVLA Low-Noise Amplifier Design

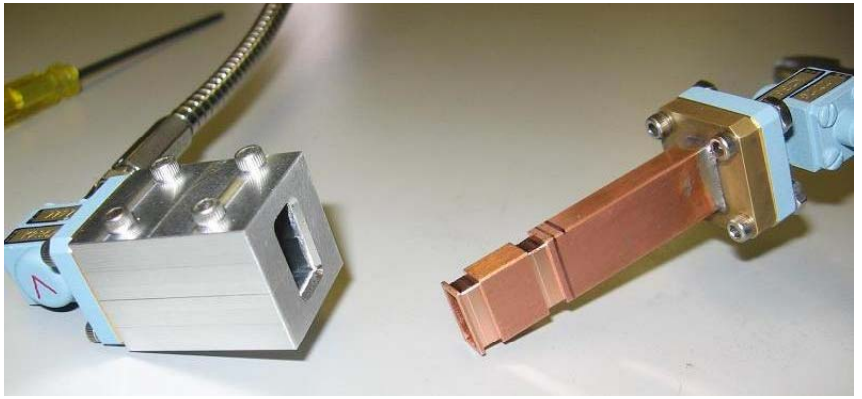




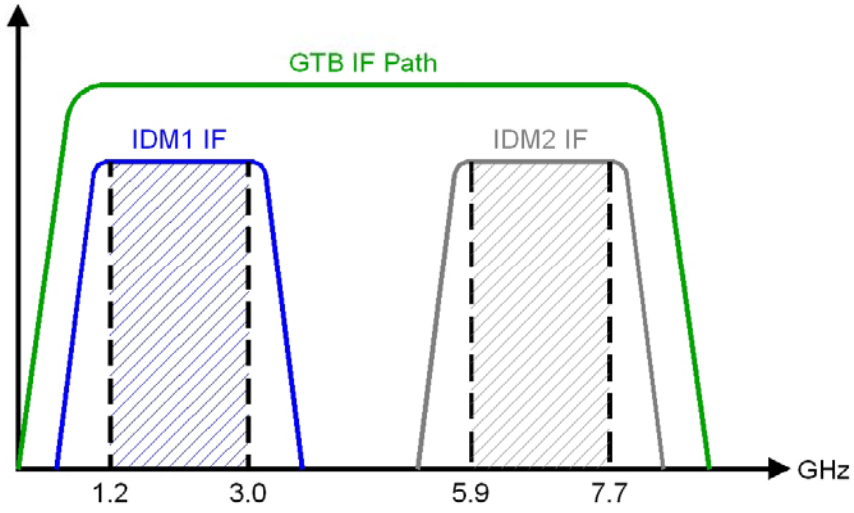
Gapped WR42 Sliding Waveguide Output Transition



- 0.360” maximum travel
- Δ length on cool-down: ~0.144”
- Stable at final temperature
- Chomerics 1285 conductive elastomer
- Ecco-foam PS102 with 3 mil Kapton

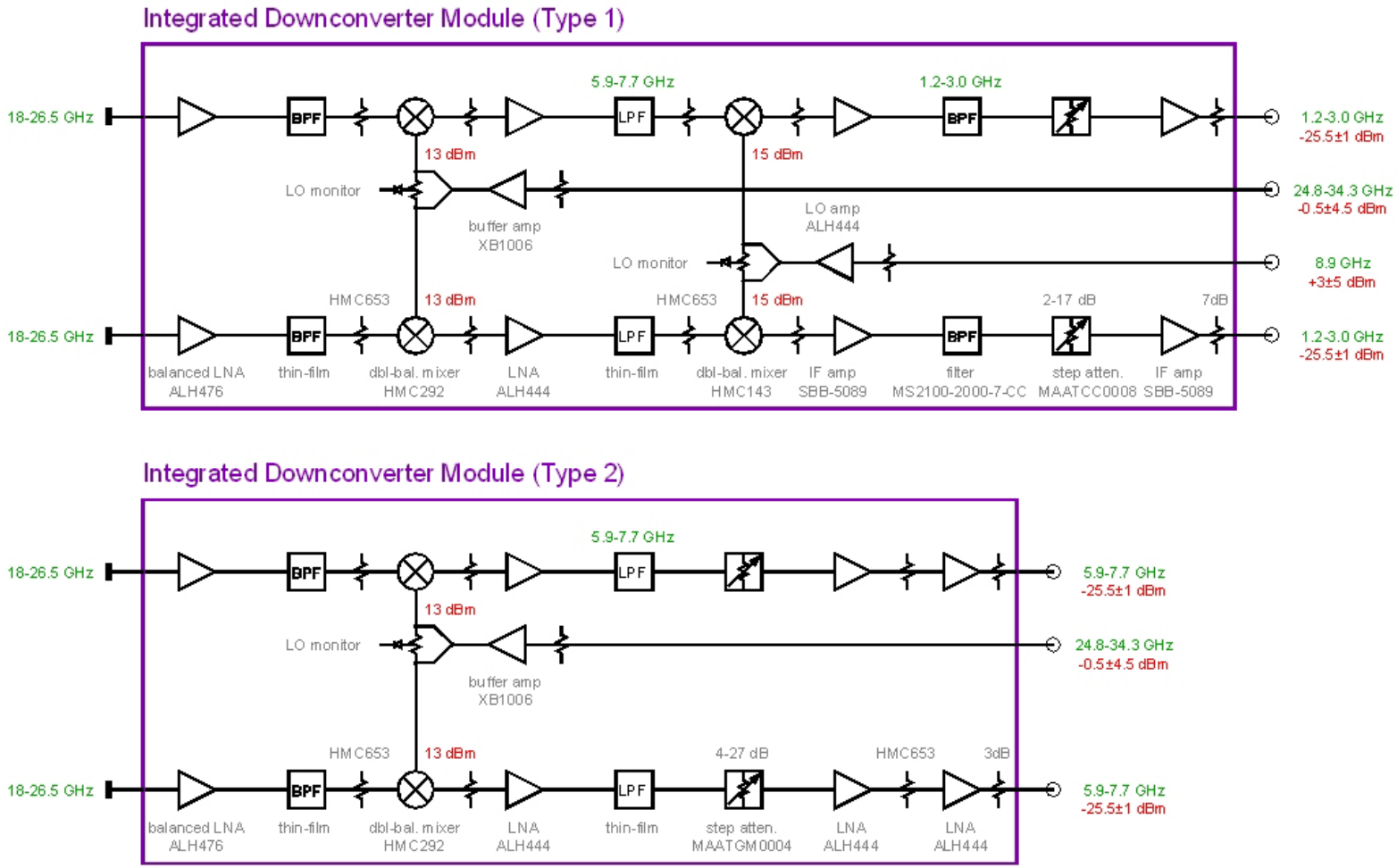


Downconverters – IF Multiplexing

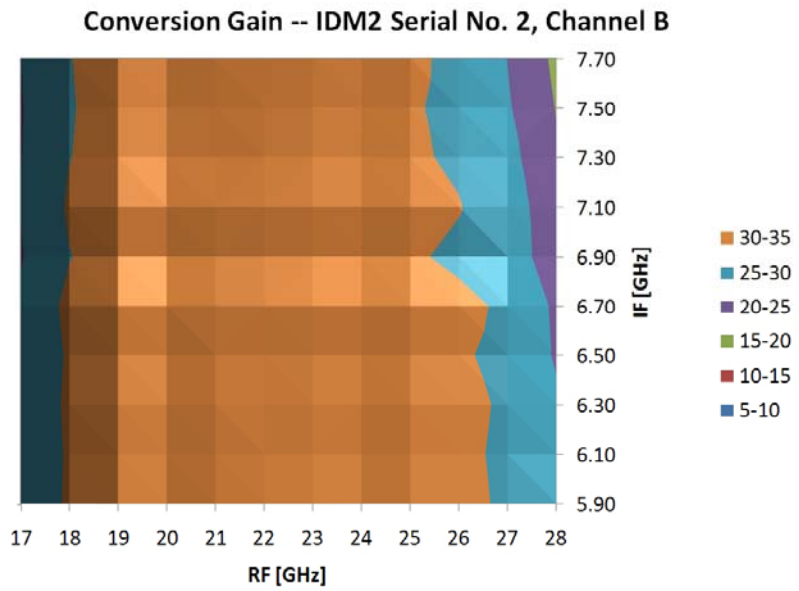


- Existing GBT IF transmission system limited to 8 channels with 8 GHz tunable bandwidth (processed in1.8 GHz windows)
- To process 14 dual-polarized pixels requires two IF's to be multiplexed onto the same fiber.
- Two different downconverters are needed.
- IF path and spectrometer upgrades are planned future improvements.

Downconverters



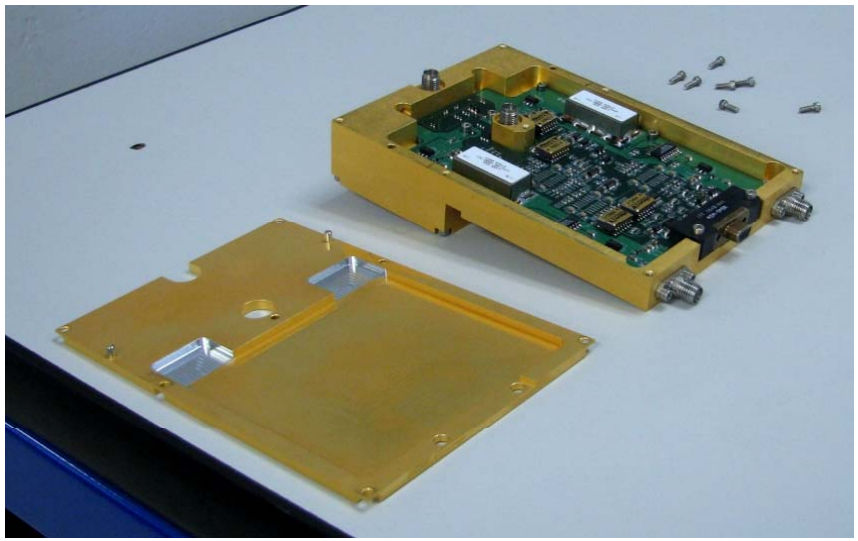
Downconverter Performance



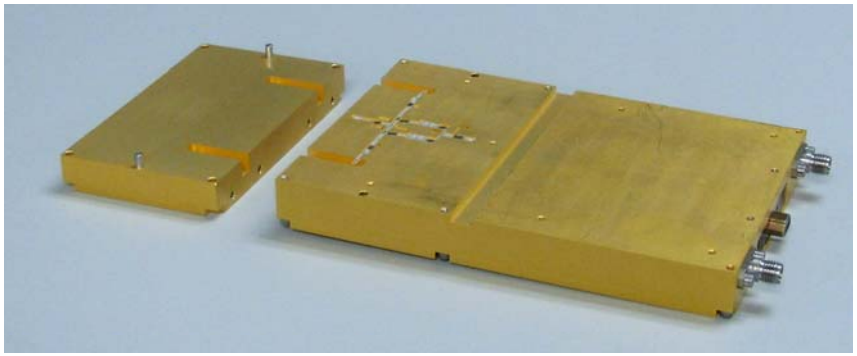
- RF Bandwidth = 8.5 GHz
- IF Bandwidth = 1.8 GHz
- LO1 Power = -0.5±4.5 dB
- LO2 Power = +3±5 dB
- Conversion Gain = 30 dB
- Gain Control = ±12 dB
- Compression Point > +10 dBm
- Image Rejection > 30 dB
- Channel Isolation > 30 dB

Downconverter Size Dominated by DC Control Functions

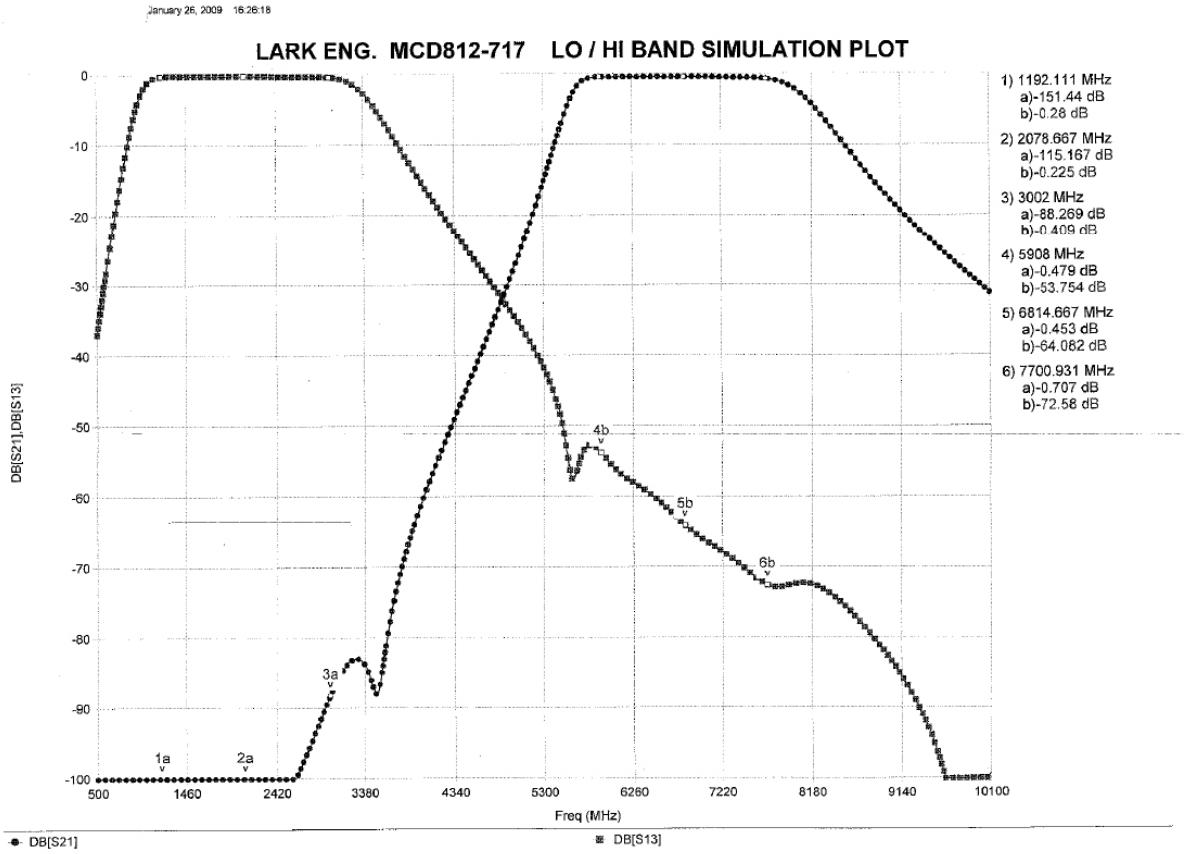
PCB Side



MMIC Side

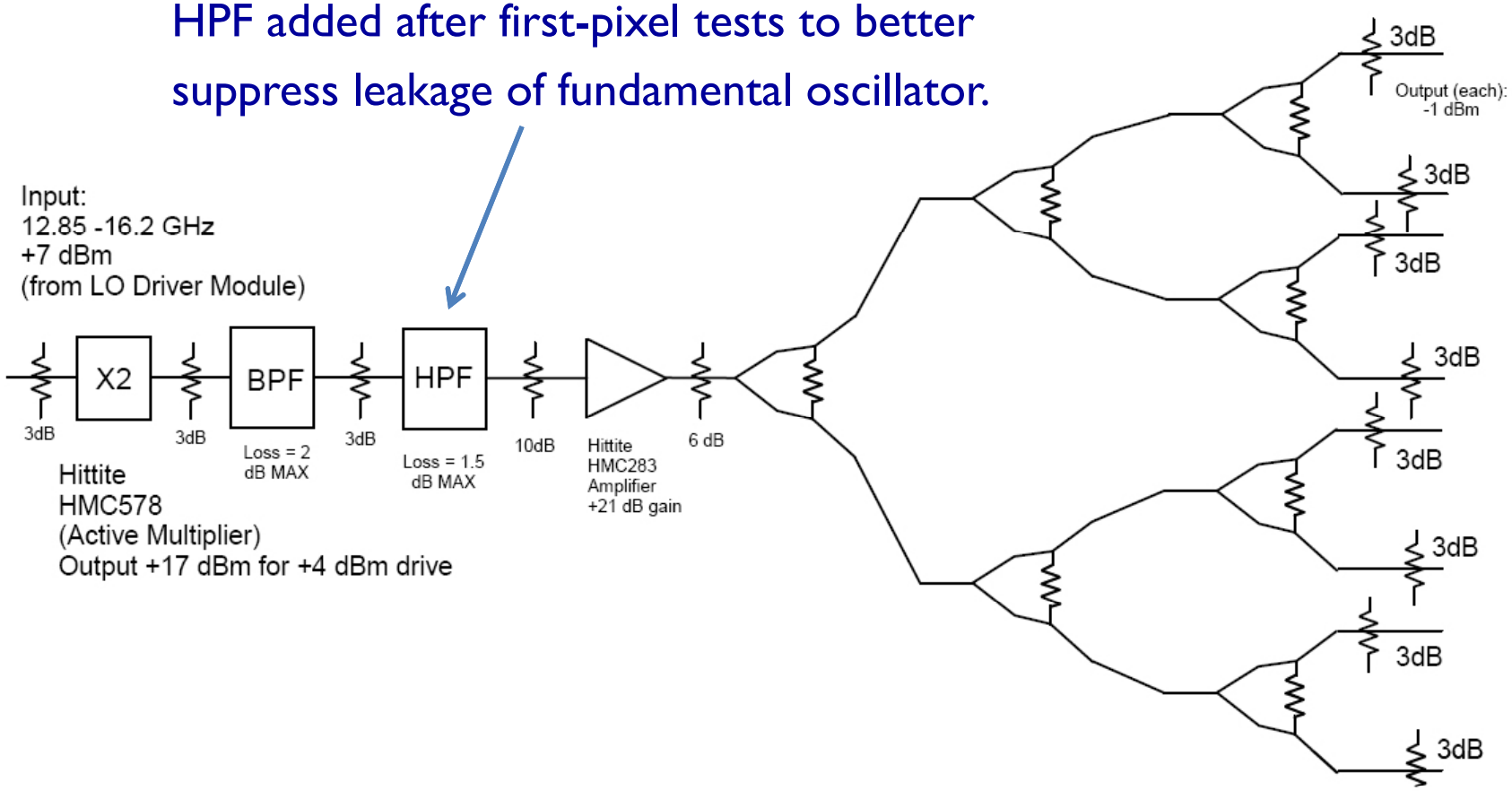


IF Multiplexer

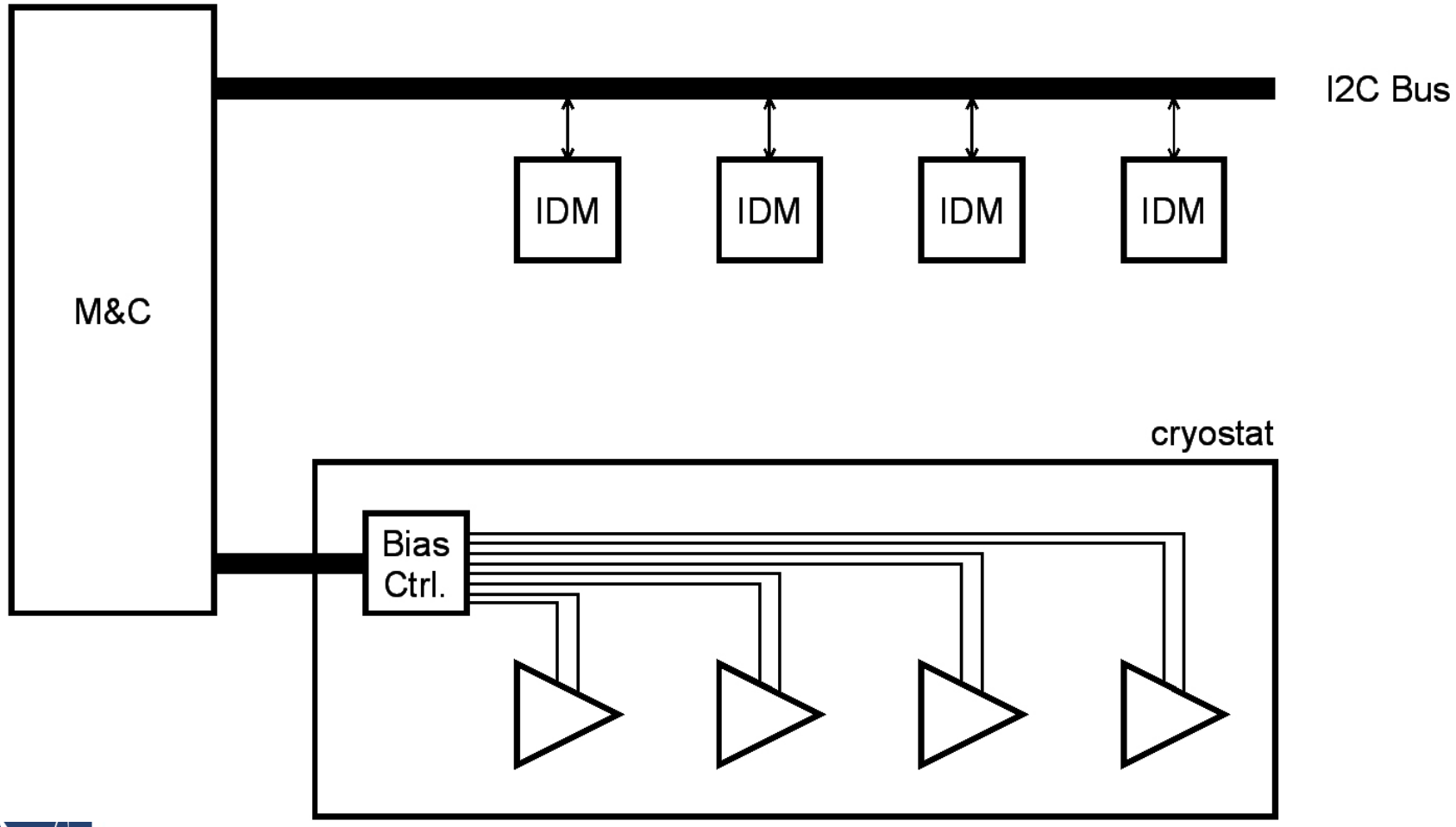


LO Distribution

HPF added after first-pixel tests to better suppress leakage of fundamental oscillator.



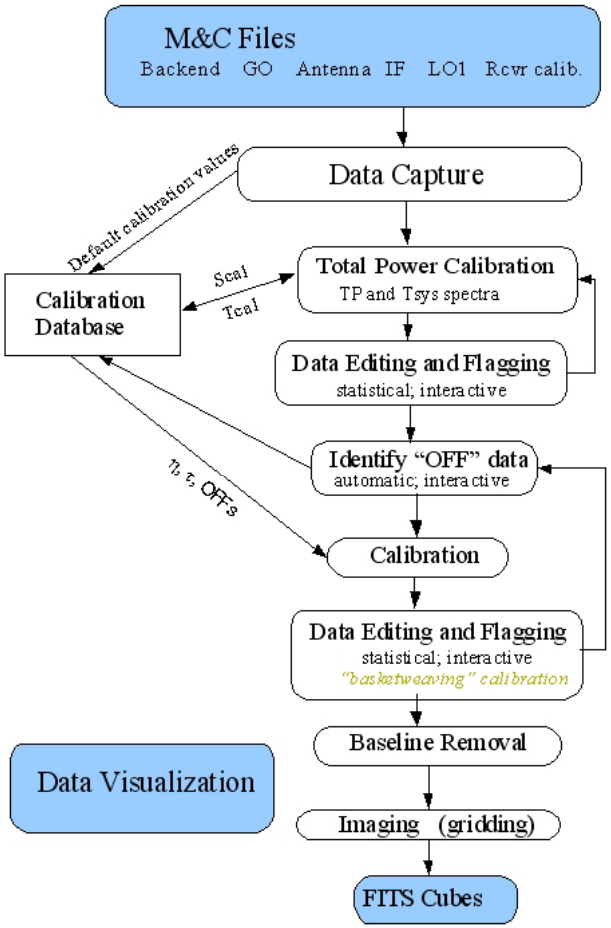
M&C Through I²C Bus to Minimize Wiring and Vacuum Feedthrus



Existing Spectrometer Modes

Spectrometer [BW]	Beams [#]	Polarizations	Windows [#]	Channels [#]	Comments
800 MHz	4	2	1	8	Tunable pairs;L1/R1 or L3/R3;L2/R2 or L4/R4;L5/R5 or L7/R7;L6R6
200 MHz	4	2	1	8	Tunable pairs;L1/R1 or L3/R3;L2/R2 or L4/R4;L5/R5 or L7/R7;L6R6
50 MHz	7	2	1	14	Seven tunable polarization pairs. (L1/R1……L7/R7)
50 MHz	4	2	2	16	Four selectable beams, one tunable polarization pair per beam; two spectral windows.
50 MHz	2	2	4	16	Two selectable beams, one tunable polarization pair per beam; four spectral windows.
12.5 MHz	7	2	1	14	Seven tunable polarization pairs. (L1/R1……L7/R7)
12.5 MHz	4	2	2	16	Four selectable beams, one tunable polarization pair per beam; two spectral windows.
12.5 MHz	2	2	4	16	Two selectable beams, one tunable polarization pair per beam; four spectral windows.

Pipeline Under Development



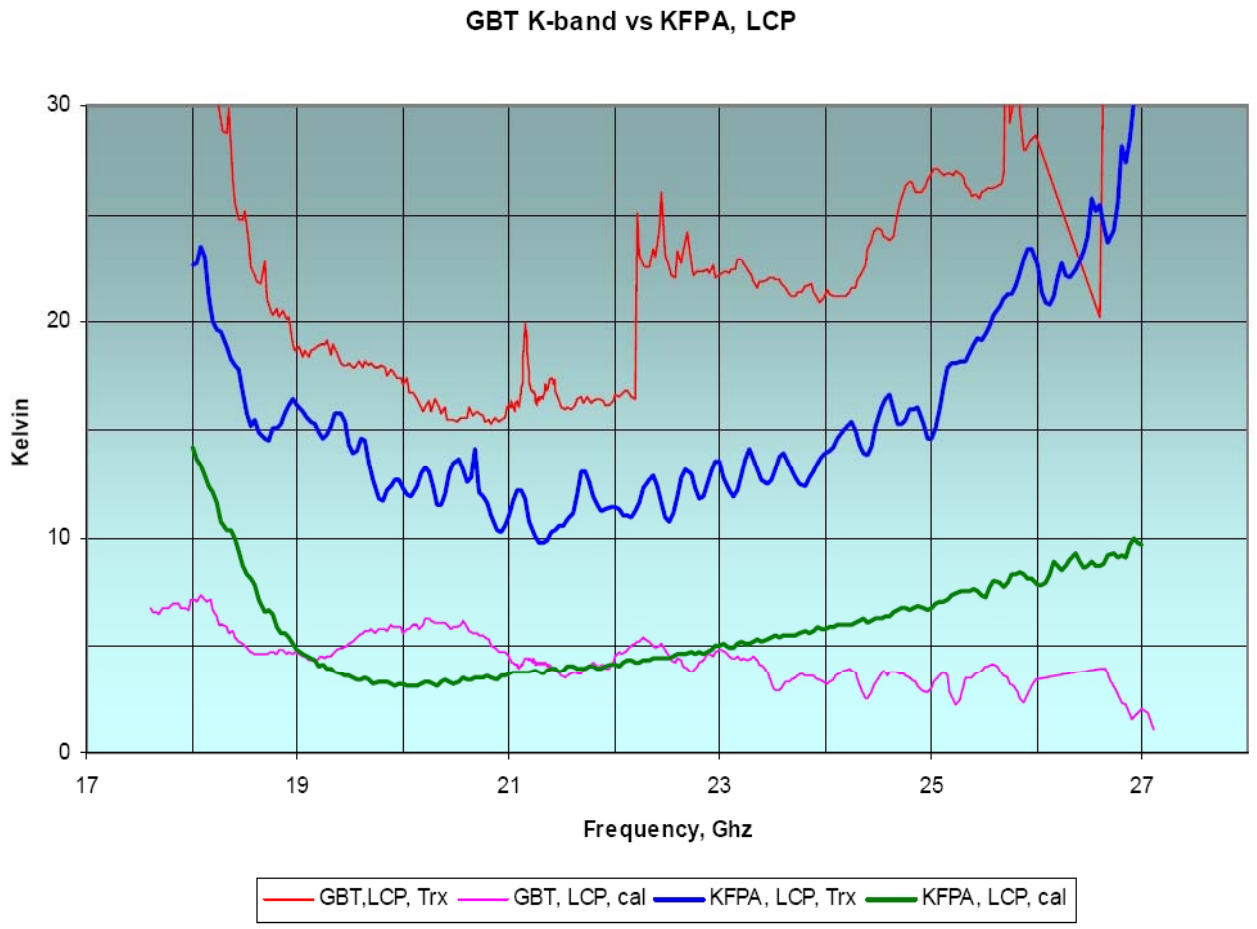
- Standard observing modes
- Meta data to capture user intent
- Interactive and statistical data flagging
- Parallel processing of beams
- Visualization of intermediate data

- Not just for KFPA - useful for data from other GBT backends as well.

Single-Pixel Prototype

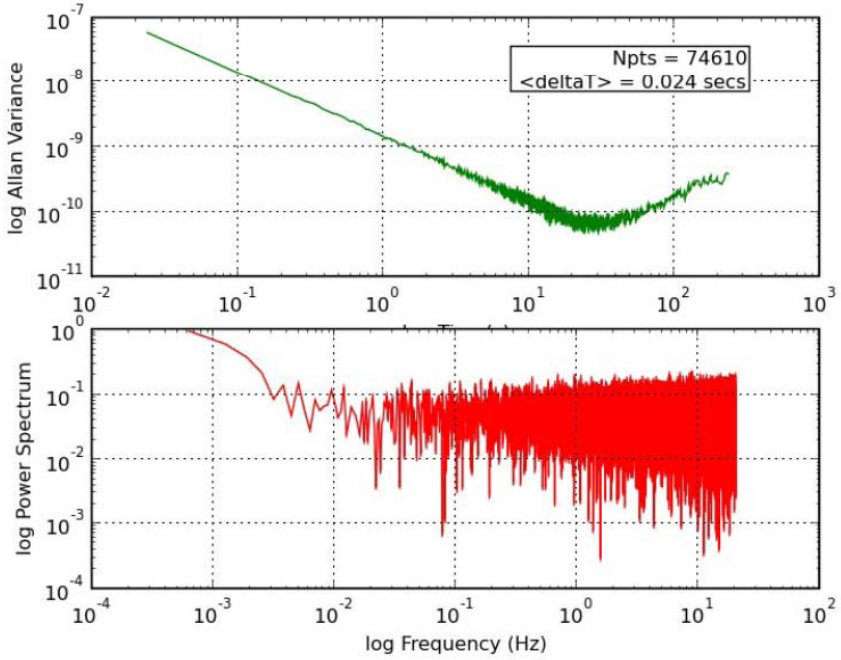
- Single feed, dual polarization
- 65” tall
- 13 lbs cooled weight, 150 lbs total weight
- CTI 350 refrigerator, 4 hr cool down
- Aluminized Mylar for radiation shield
- Installed in a 24” dia turret hole
- Will keep for use as a test bed

Laboratory Testing – Noise Temperature

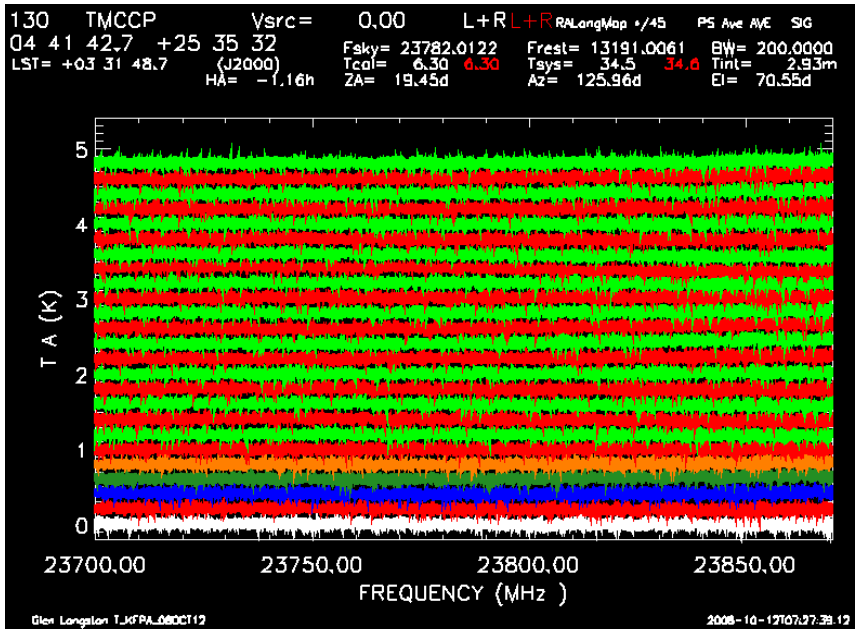


Laboratory Testing – Stability Checks

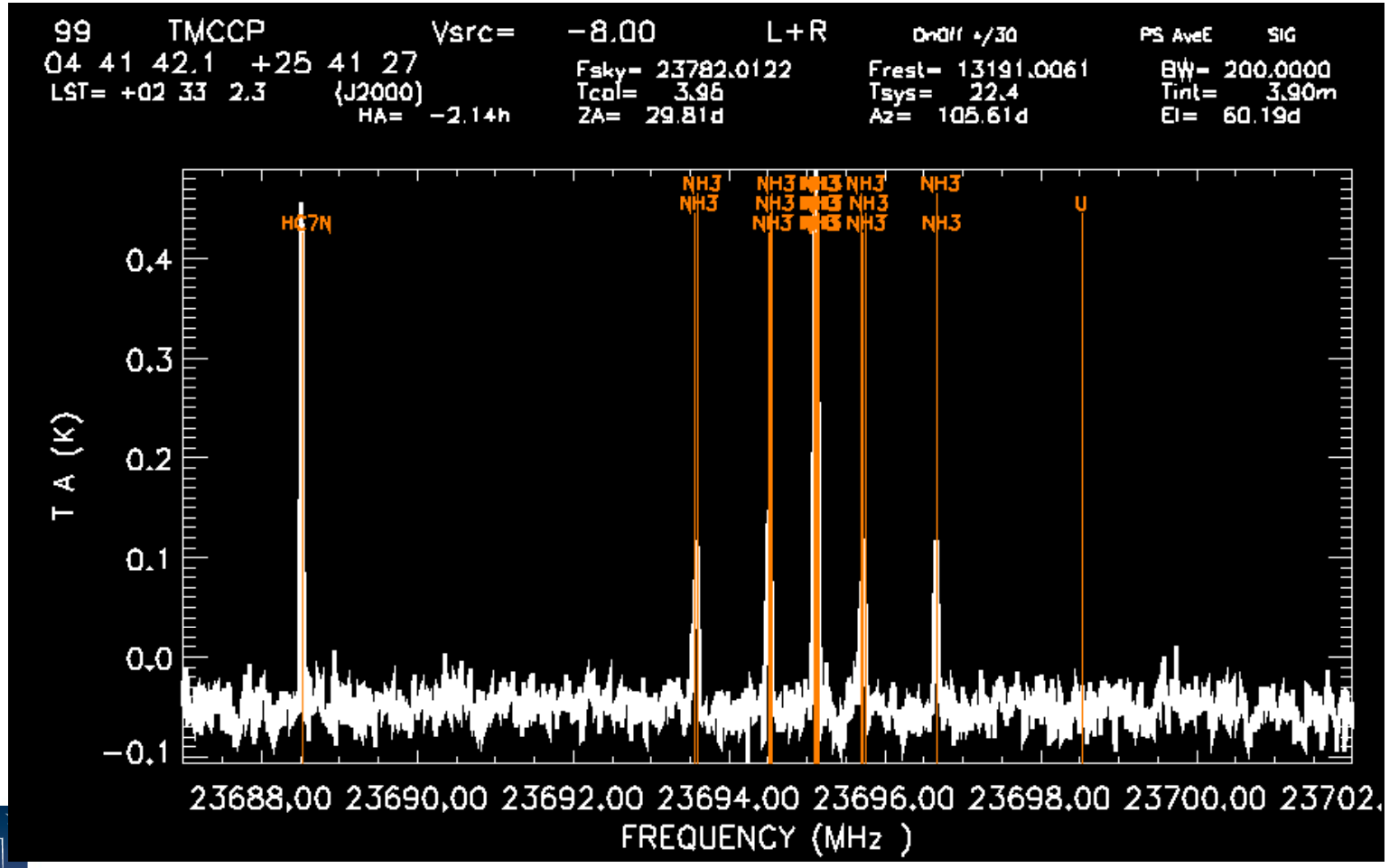
Alan Variance and PSD



Repeated 90s Baselines

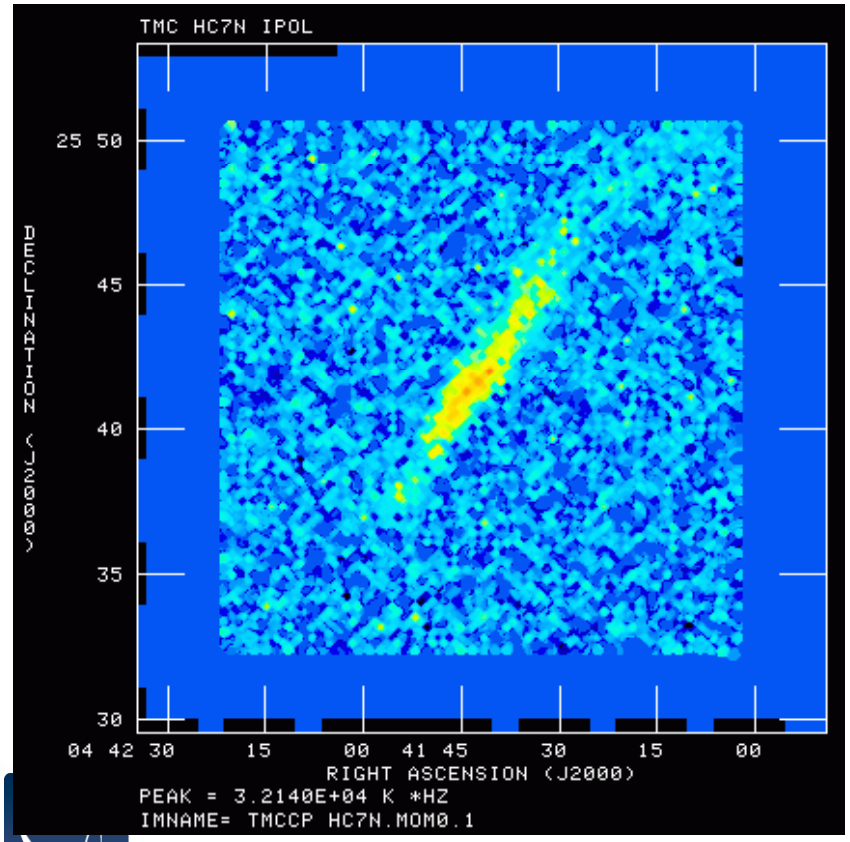


Single Pixel On Telescope – HC7N and Ammonia 1-1 Transitions

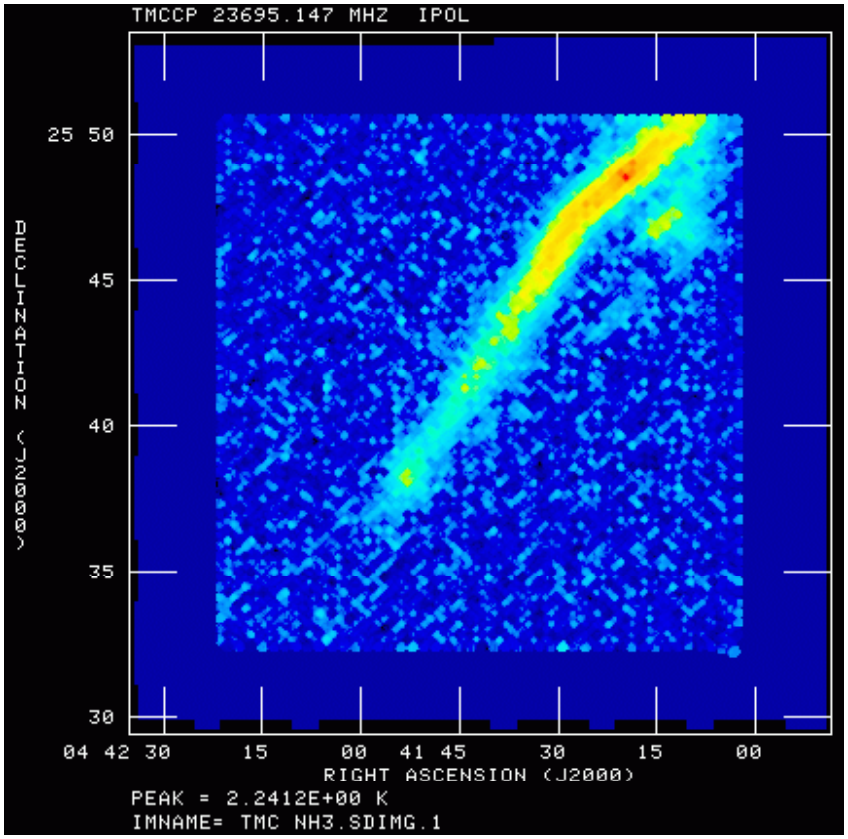


Single Pixel on Telescope – Taurus Molecular Cloud (1 second integrations)

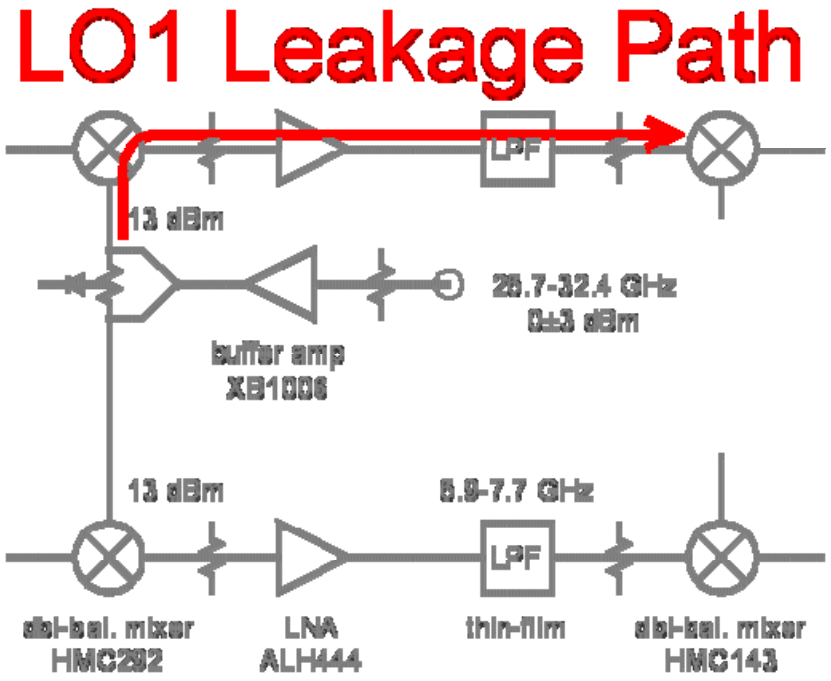
HC7N



NH3

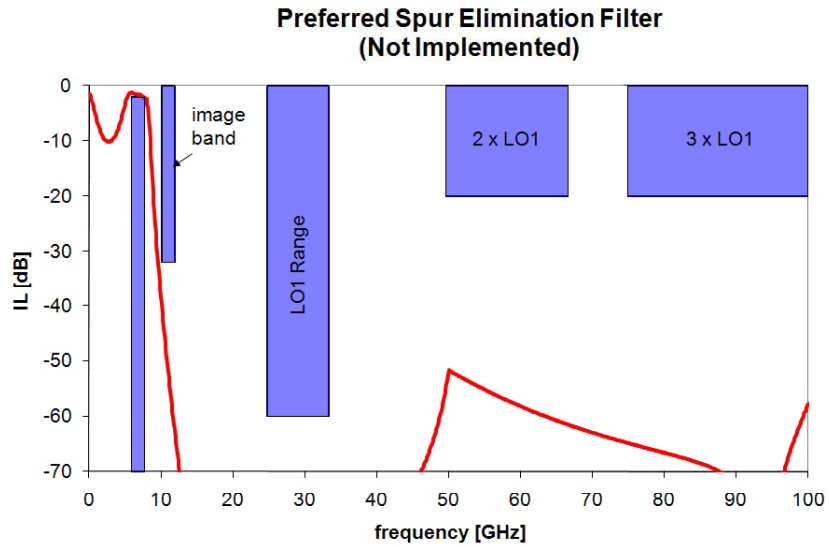


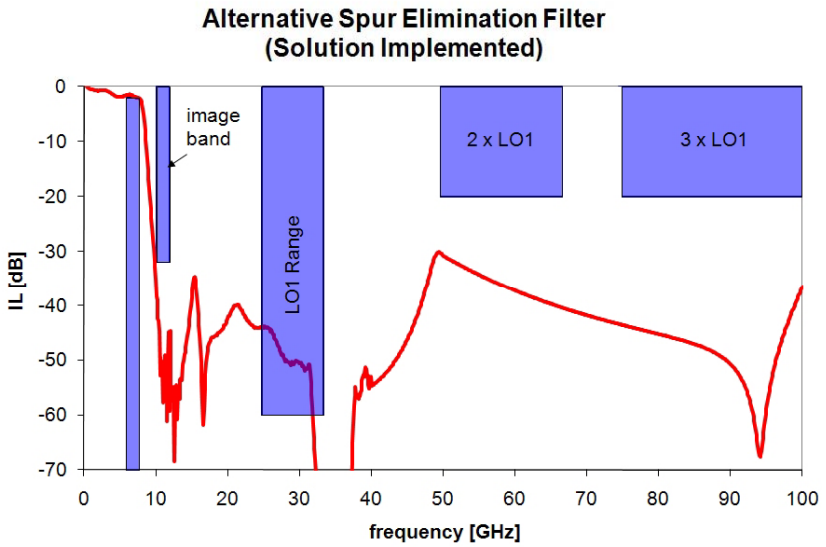
Design Issue – LO Spurs



- IF Multiplexing forced two-stage mixing approach for one IDM
- IF plan designed to avoid spurs up to 5th order
- Higher-order spurs inevitable at some level - we found one that was 14th-order! (3LO1-11LO2)

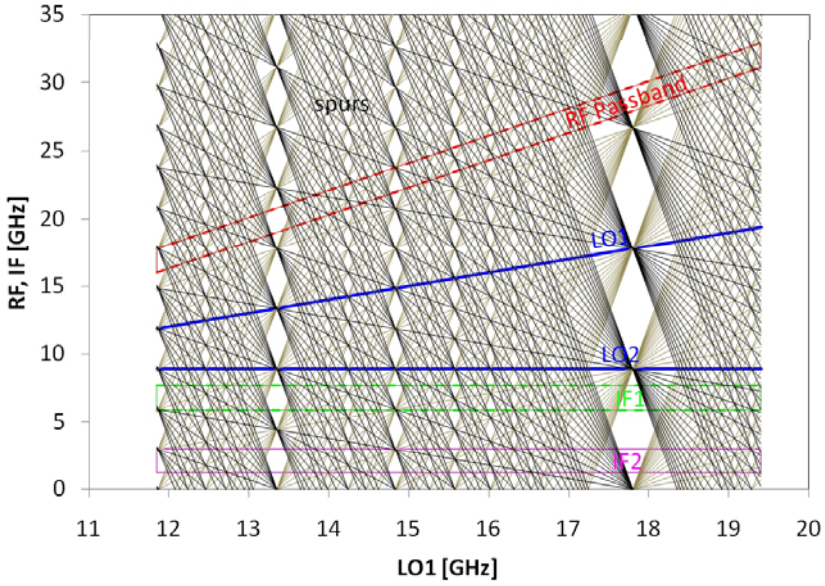
First Solution: Filtering



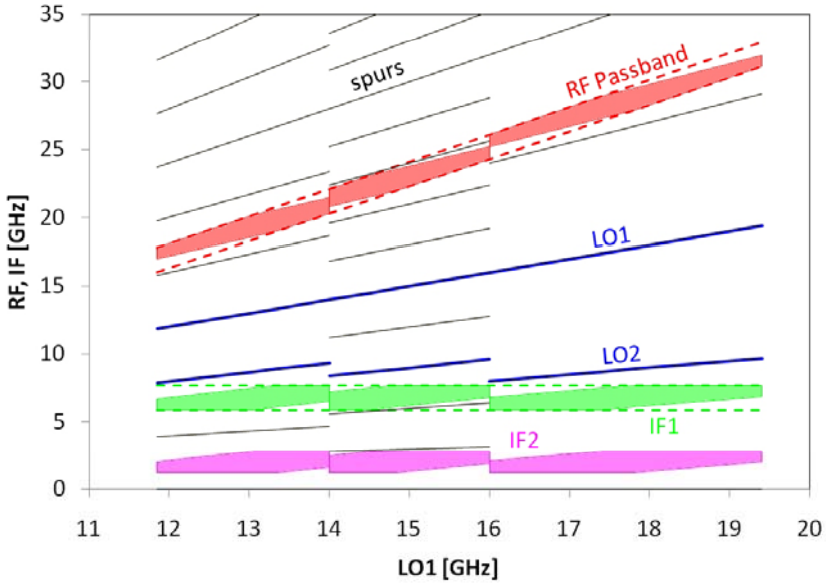


Better Solution: Tune to Avoid

Incommensurate Tuning



Commensurate Tuning



Best Solution: Don't Use Two LO's!

Especially for

- an integrated receiver
- a single-dish telescope
- a focal-plane array (distribution losses require LO power saturation to ensure uniformity of gain)

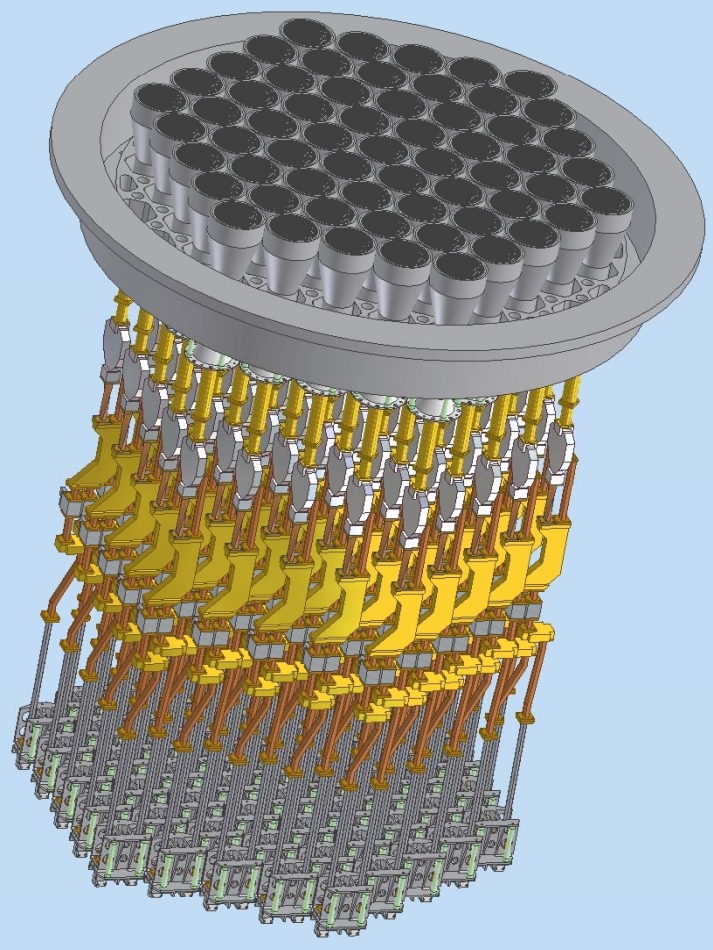
Seven-Pixel Array

- Dual polarization, 14 IF outputs
- Overall size 65” tall, 23” dia
- Designed for 24” dia turret hole
- 90 lbs cooled weight, 280 lbs total
- CTI 350 refrigerator
- One pressurized radome to cover all feeds
- Reinforced dewar top and bottom plates. MIC6 cast aluminum for machining stability.

Project Timeline

- 4/16/2007 - Initial Proposal
- 10/4/2007 - Proposal Accepted
- 2/28/2008 - Conceptual Design Review
- 8/22/2008 - Single Pixel Construction Complete
- 12/31/2008 - GBT and Laboratory Tests Complete
- 1/31/2009 - Critical Design Review
- 12/7/2009 - Seven-Pixel Construction Complete
- 1/31/2010 - System Integration and Lab Tests Complete
- 4/31/2010 - Telescope Tests Complete
- 11/8/2010 - Commissioning Complete

Future Work: Sixty-Pixel Array?



Probably not.

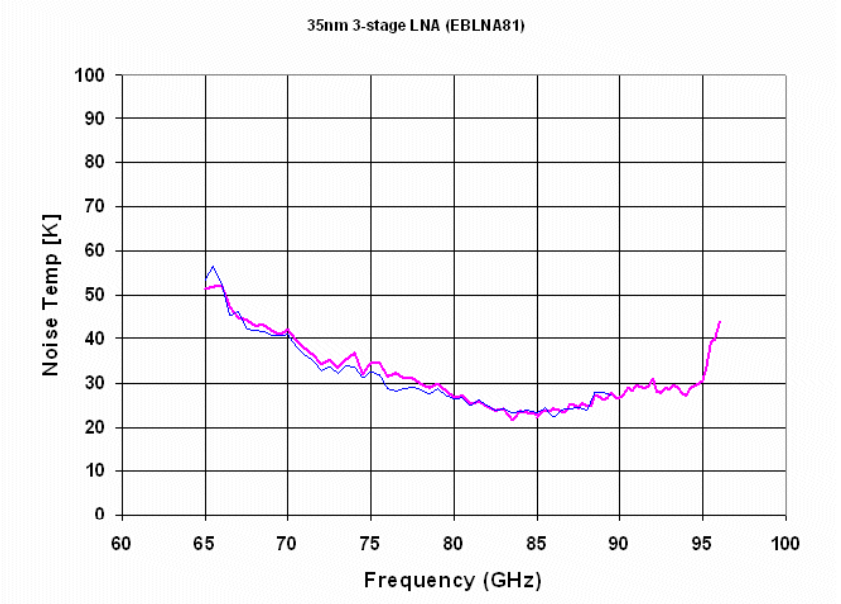
- Many challenges (size, weight, thermal, power dissipation, maintenance requirements, etc.)
- Would require more integration of cold electronics

- Latest from Science team is that most objects of interest are no bigger than 7-beam footprint anyway.

Future Work: A W-Band (3mm) FPA

- There is great interest on many fronts for a W-Band Heterodyne Focal Plane Array on the GBT
- 100 elements?
- 65-90 GHz or 85-115 GHz?
- Could make use of a new MMIC amplifier with 23K minimum noise at 85 GHz (E. Bryerton, using NGST 35nm InP process)

- MUST include greater integration of cold electronics.



Danke!